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METHODS FOR PREDICTION OF ATMOSPHERIC EFFECTS ON LASER GUIDANCE SYSTEMS

U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND

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This report describes mathematical models which predict effects of atmospheric turbulence, molecular absorption and scattering, aerosol absorption and scattering, and radiative transport.

Turbulence-induced angle-of-arrival fluctuations of a laser target designator are formulated to permit calculation of the fluctuation power spectrum. A numerical procedure employing the fast Fourier transform is used to convert the frequency-dependent power spectrum into the time domain

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ABSTRACT (Concluded)

giving angular beam wander. A separate computation gives the angular beam-spread due to atmospheric turbulence.

Descriptions of other models to determine molecular line absorption and aerosol absorption and scattering are also given. Models developed during this effort also provide first-order radiative transfer predictions and a multiple scattering model using Monte Carlo predictions. Utilization instructions are included for each of the models.

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I. INTRODUCTION

Laser guidance systems operating in the atmosphere are affected by several phenomena which tend to degrade the transmitted laser beam and result in poorer performance than would be obtainable in vacuum transmission. Of these phenomena, the major contributors to beam degradation are direct attenuation of the beam's energy by absorption, spreading and motion of the beam due to random index-of-refraction variations within the atmosphere, and scattering of the electromagnetic radiation by atmospheric particles.

Direct attenuation of the transmitted energy occurs from molecular absorption by the various constituents in the atmosphere and absorption by aerosol particles present in the atmosphere. Molecular absorption occurs at selected lines or frequencies and varies greatly over fairly narrow frequency intervals. Aerosol absorption, however, remains nearly constant for a given particle over wide ranges in frequency of the transmitted energy. Methods are presented in this report for determining the absorption coefficients for molecules and aerosols.

Index-of-refraction variations in the atmosphere occur from heat transfer processes which produce air temperature inhomogeneity or turbulence. Movement of these random fluctuations in air temperature across the path of a transmitted laser beam caused by wind or beam sluing result in the beam wandering and spreading about its original aim point. Thus, the energy distribution or "spot" produced at a distance downrange of the transmitter does not remain constant, but enlarges and wanders about the "target" area. This turbulence-induced beam "jitter" or wandering adds an additional component to that already produced in the guidance system. This report describes a new analytical method for rapidly predicting spot movement and size as a function of transmitter characteristics, refractive index structure constant, and effective wind speed across the beam.

Air molecules and other particles such as dust, haze, fog, or smoke, which are present in the atmosphere, degrade a laser beam by scattering part of the energy out of the path of the beam. For particles very small relative to the laser wavelength, the angular distribution of the scattered energy can be easily determined. For particle sizes of the same order as the wavelength or larger, however, the theory becomes more complex and extensive calculations are required. Analytical methods suitable for making these calculations are well developed for most particles of interest, but the physical data required are not adequate in many cases. For example, the complex indices-of-refraction and particle size distributions of many aerosols are not well known.

This effort was undertaken to provide methods that could be used to make predictions of the effects of the atmosphere on a terminal homing laser guidance system. Available procedures and methods were

reviewed and those adequate for the present application have been adapted for use. Scientific support was obtained to provide help in developing new procedures and modifying existing models. In particular, the efforts of Dr. D. L. Fried of Optical Sciences Consultants provided the basis for the turbulence beam wander model and the support of W. G. Blattner, D. G. Collins, and M. B. Wells of Radiation Research Associates was obtained to modify their existing Monte Carlo radiation transport model. The molecular and aerosol attenuation models were obtained from Dr. A. Miller of New Mexico State University and Dr. R. B. Gomez at the Army Atmospheric Sciences Laboratory. An additional model for predicting first-order radiation transport for a laser designator system was developed in-house.

Descriptions are presented in the following sections of the models developed for predicting atmospheric effects encountered by a transmitted laser beam, and the Appendix provides utilization instructions. Fortran listings of the in-house developed procedures are included.

II. TURBULENCE-INDUCED BEAM WANDER MODEL

For predicting turbulence-induced wander of the laser transmitter beam the model developed by Fried [1] for calculating the power spectrum of angle-of-arrival fluctuations is used in a numerical procedure employing the fast-Fourier transform (FFT) to convert the frequency dependent power spectrum into the time domain giving the angular jitter of the beam. In this method, the power spectrum defined as the Fourier transform of the angle-of-arrival temporal coherence function is expressed as

$$F_\alpha(f) = 4\int_0^\infty \cos(2\pi f\tau) C_\alpha(\tau)\,d\tau \quad ,$$

where $C_\alpha(\tau) = \langle\alpha(t)\alpha(t+\tau)\rangle$ is the temporal coherence function of the angle-of-arrival fluctuations.

In the numerical procedure, the turbulent region between the transmitter and target (Figure 1) is subdivided into N segments of length ΔZ_i and the calculation performed for each segment is

$$F_{\alpha,i} = 1.32(10^{-2})\left(\frac{\lambda}{D_s}\right)^2\left(\frac{D_s}{r_{o,i}}\right)^{5/3} f_{o,i}^{\;-1/3}\, f^{-2/3}\, G_\alpha\left(\frac{f}{f_{o,i}}\right) \quad ,$$

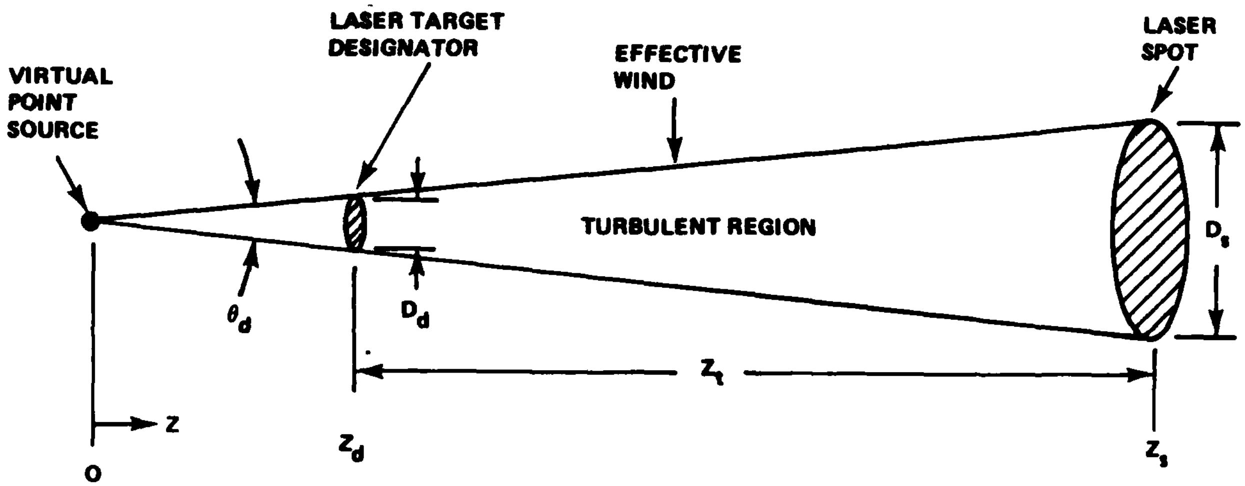

Figure 1. Geometry for turbulence-induced beam wander model.

where

λ = the laser wavelength

D_s = the spot diameter

$r_{o,i}$ = the coherence length of segment i defined by

$$r_{o,i} = \left[16.7\, C^2_{N,i}\left(\frac{\Delta Z_i}{\lambda^2}\right)\left(\frac{Z_i}{Z_s}\right)\right]^{-3/5} \quad ;$$

$f_{o,i}$ is a reference frequency given by

$$f_{o,i} = \frac{V_{eff,i}}{\pi\, D_s\left(\frac{Z_i}{Z_s}\right)}$$

and

$G_\alpha(f/f_{o,i})$ is a function which can be approximated by

$$G_\alpha\left(\frac{f}{f_{o,i}}\right) = \begin{cases} 1 & , \text{ if } 0 \le f < 0.332\, f_{o,i} \\ 1.12 - 0.361\left(\frac{f}{f_{o,i}}\right) & , \text{ if } 0.332\, f_{o,i} < f < 3.1\, f_{o,i} \\ 0 & , \text{ if } 3.1\, f_{o,i} < f \end{cases} \quad .$$

$C^2_{N,i}$ is the refractive index structure constant of segment i and Z_i is the distance from the virtual point source to the center of segment i. $V_{eff,i}$ is the effective wind velocity across the beam at segment i and can include the effects of beam sluing by combining with the actual crosswind velocity according to

$$V_{eff,i} = V_{w,i} \pm \dot{\theta}(Z_i - Z_d) \quad ,$$

where the plus or minus sign is chosen to account for the wind being opposed to or in the same direction as the angular sluing. The power spectrum for frequency f is

$$F_\alpha(f) = \sum_{i=1}^{N} F_{\alpha,i}(f) \quad .$$

The variance of the power spectrum is the integral over frequency, or

$$\sigma^2 = \sum_{i=0}^{M} F_\alpha(f_i)\Delta f \quad ,$$

where M is the number of frequency values chosen.

Values obtained for the power spectrum are next combined with a set of random values chosen so as to have zero mean value and unity variance. This gives a random sequence of values having the same variance as the calculated power spectrum. The relation used to form the random sequence is

$$N_r(f_i) = N_{r,i} \sqrt{F_\alpha(f_i)/\Delta t} \quad ,$$

where $N_{r,i}$ is one of the normally distributed random values and Δt is the time interval between values in the time domain chosen so that

$$M \Delta f \Delta t = 1 \quad .$$

A symmetric array of 2M values is obtained by folding the $N_r(f_i)$ array to give an equal number of negative frequency values. Fourier transforming the resulting 2M array gives an ordered sequence of values representing the time interval $-T \leq 0 \leq T$, where $T = M\Delta t$. The second half of this sequence represents one component of beam jitter. A second set of independent values is obtained in the same manner for the other component of angular jitter to give spot centroid motion at the target.

To obtain beam jitter for the target-to-seeker path, the power spectrum of angle-of-arrival fluctuations is determined by a similar procedure except that angle-of-arrival isoplanatism effects must be considered. The complete procedure has been discussed in detail by Fried [2]. Total power spectrum for the two paths becomes

$$F_T(f) = F_\alpha(f) + F_V(f) \quad ,$$

where $F_V(f)$ is the power spectrum associated with the viewing process from the seeker.

The method for target spot size determination proposed by Fried [2] is to make use of his short-exposure resolution theory for the turbulence-induced and diffraction-limited beamspread. The calculation of the effective beamspread becomes

$$\theta_t = \theta_r \, \Phi\left(\frac{D_d}{r_o}\right) \quad ,$$

where $\theta_r = 1.128\ \lambda/r_o$ and the function $\Phi(D_d/r_o)$ is determined by evaluating the integral

$$\Phi\left(\frac{D_d}{r_o}\right) = \left\{\frac{16}{\pi}\left(\frac{D_d}{r_o}\right)^2 \int_o^1 u\,du \left[\cos^{-1} u - u\left(1 - u^2\right)^{1/2}\right]\right.$$

$$\left.\times \exp\left[-3.44\left(\frac{D_d}{r_o}\right)^{5/3} u^{5/3}\left(1 - u^{1/3}\right)\right]\right\}^{-1/2} \quad ,$$

where r_o is the coherence length for the designator path.

Total angular beamspread is determined by combining with the transmitter optical divergence according to

$$\theta_s = \left(\theta_t^2 + \theta_d^2\right)^{1/2}$$

and the corrected spot size at the target including turbulence, diffraction, and designator optics becomes

$$D_s' = D_d + \theta_s Z_t \quad .$$

Comparisons of the results of calculations of beamspread made by this method with the methods of others have shown differences in spot size which become quite large under conditions of strong turbulence. Resolution of these differences to determine a preferred method of calculating spot size awaits an experimental validation.

III. MOLECULAR AND AEROSOL ATTENUATION MODELS

Methods for the prediction of molecular and aerosol absorption and scattering developed for other programs were adapted for use in the present effort. Models developed for the Army Atmospheric Sciences Laboratory by Miller et al. [3] and Gomez et al. [4] are particularly applicable to the kinds of problems considered. Brief descriptions of these two models are presented in this section. Input data instructions for making calculations are included in the Appendix.

The molecular absorption and scattering model [3] uses the AFGL (formerly AFCRL) line parameters compilation [5] and computes high resolution molecular absorption, molecular continuum absorption, and Rayleigh scattering coefficients. Property data for the 1962 US Standard Atmosphere are built into the model, or alternate tables of atmosphere data may be user supplied. Line shape options include Lorentzian, generalized Voigt, and collision narrowed line profiles. The output provided by this model are the absorption coefficient, Rayleigh scattering coefficient, and transmittance for the frequency range specified.

Calculations performed by the attenuation model [4] for aerosols are based on standard Mie theory for homogeneous spheres and provide the scattering and absorption coefficients as well as the phase function data necessary for radiative transfer calculations. Input data required are the laser wavelength, index-of-refraction, size distribution, and particle density of the scattering medium. Several size distributions are provided as "built-in" options, or the user may supply size distribution and particle density from measured data. Output from this model may be obtained in punched card form for use as input into radiative transfer models or this model may be used simply as a subroutine in the RT model as in the present application.

IV. RADIATION TRANSPORT MODELS

To predict the effects of radiation absorption and scattering on a laser guidance system, a method to determine the amount of energy reaching the target and receiver is required. Under conditions of only moderate aerosol densities, methods which consider first-order or single scattering effects are usually adequate. Under conditions of very dense aerosols such as heavy fog or smoke in the transmitting region, however, second and higher order scattering effects become important,and more complex procedures are required. Models using both methods of approach to radiation transfer were developed during this effort. An existing Monte Carlo method for performing multiple scattering calculations modified and adapted to the present problem is described in a separate report [6]. The remainder of this section presents a method employing first-order scattering.

The geometry for the model presented here consists of a laser transmitter, an absorbing and scattering medium, the target, and a receiver viewing the target (Figure 2). The target receives energy by direct transmission and by scattering from aerosol particles located in the beam and reflects part of the energy received. Energy reaches the receiver by reflection from the target and by scattering from aerosol particles in the transmitter beam located within its field-of-view. The transmitting range is divided into segments and the procedure is used to calculate the energy scattered from each segment to the target and to the receiver. The target area is divided into annular rings to determine the distribution of scattered and directly transmitted energy.

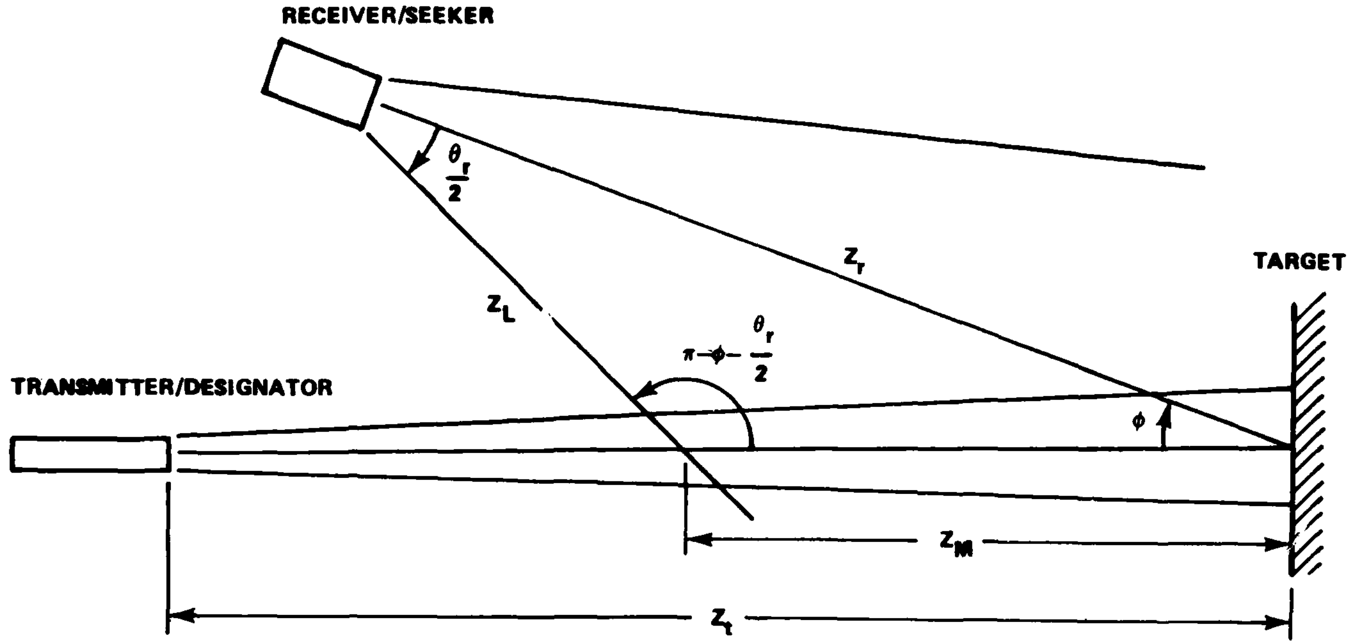

Figure 2. Geometry for first-order radiative transfer model.

The basic relationship used in making the calculations of energy scattered to each area receiving radiation from a segment of length ΔZ becomes

$$P_{s,i} = P_o\, e^{-\sigma Z_i}(1 - e^{-\sigma \Delta Z})\,\omega P(\theta_i)\left(\frac{A_r}{r_i^2}\right)e^{-\sigma r_i} \quad ,$$

where

P_o = the transmitter output power

σ = the total attenuation coefficient due to scattering plus absorption

Z_i = the range to the center of the scattering segment

ω = the albedo or ratio of scattering to total extinction

$P(\theta_i)$ = the normalized phase function at the angle θ_i to the receiving area A_r

r_i = the path distance from the center of the scattering segment to the receiving area and the last term accounts for attenuation along r_i.

The total energy reaching the target area from N segments plus directly transmitted radiation is

$$P_t = P_o\, e^{-\sigma Z_t} + \sum_{i=1}^{N} P_{s,i} \quad .$$

The scattered energy is summed over all the annular areas of the target and the sum over N segments gives the total energy scattered to the target (neglecting higher order scattering). For the directly transmitted radiation, a gaussian distribution is assumed and the average intensity is computed for each annular area from scattered and directly transmitted radiation.

Reflected energy from the target (assumed to be a diffusely reflecting surface) that reaches the receiver is computed by the relation

$$P_{r,t} = \rho P_t \frac{\cos \varphi}{\pi}\left(\frac{A_r}{Z_r^2}\right)e^{-\sigma Z_r} \quad ,$$

where

ρ = the target reflectivity

φ = the receiver viewing angle to the target normal

A_r = the receiver area

Z_r = the range from the target to receiver.

For a receiver with field-of-view θ_r viewing the target at angle φ to the incident beam, the beam length Z_M seen by the receiver is

$$Z_M = \frac{Z_r \sin\left(\frac{\theta_r}{2}\right)}{\sin \gamma} \quad ,$$

where $\gamma = \pi - \phi - \theta_r/2$ and the distance from the receiver to the beam intersection point Z_L is given by

$$Z_L = \frac{Z_r \sin \varphi}{\sin \gamma} \quad .$$

The path length Z_M is divided into M segments of length ΔZ_M; the relation used to determine the energy reaching the receiver from all segments becomes

$$P_{r,s} = \sum_{i=1}^{M} P_o \, e^{-\sigma Z_i}\left(1 - e^{-\sigma \Delta Z_M}\right) \omega P(\gamma_i) \left(\frac{A_r}{Z_{L_i}^2}\right) e^{-\sigma Z_{L_i}} \quad ,$$

where γ_i is the angle (counterclockwise) from each segment to the receiver and Z_{L_i} is the distance from the center of each segment to the receiver. The total energy reaching the receiver by reflection and scattering becomes

$$P_r = P_{r,t} + P_{r,s} \quad .$$

In practical cases of interest to the Army, the laser transmitting region consists of a clear atmosphere over most of the path and a smoke cloud or heavy aerosol concentration over the remaining distance. Provision has been made in the model described here by the introduction of

a parameter, Z_{cloud}, giving the distance from the transmitter to the beginning of the aerosol cloud. Then, in performing the computations, if $Z_i < Z_{cloud}$, no absorption or scattering takes place. When $Z_i \geq Z_{cloud}$, the computations are performed as previously shown. Similarly, in performing the computation of energy reflected and transmitted to the receiver, no attenuation takes place once the cloud has been exited.

Appendix. UTILIZATION INSTRUCTIONS

All of the models discussed in this report have been adapted for use on the Army Missile Materiel Readiness Command (MIRCOM) CDC 6600 computer at Redstone Arsenal. This appendix describes briefly the input data required for each of the computer models and contains Fortran listings of the in-house developed models. Instructions for use of the Monte Carlo radiation transport model is presented in a separate report prepared by Radiation Research Associates personnel [7].

1. Turbulence-Induced Beam Wander

Required input data for the turbulence-induced beam wander model consists of run options, laser transmitter characteristics, range and time period, tables of refractive index structure constant, C_N^2, and windspeed for transmitter and seeker paths, array sizes for frequency, and range segments. The following list contains input data card formats, variables read on each card, and a description of each variable. The CDC 6600 computer program library must be attached for each run.

Card	Description
1	IOPT, NRUNS Format (2I4) IOPT = 1, calculations for designator path only = 2, calculations for designator and receiver paths NRUNS = Number of cases to be run. A complete set of the remaining data cards are required for each case.
2	LAMB, DIAM, THET, TDOT, RANG, TIME Format (6E10.4) LAMB = laser wavelength in meters DIAM = diameter of laser designator aperture in meters THET = beamspread angle of laser designator in radians TDOT = angular slue rate of laser designator in radians/second RANG = distance from designator to target in meters TIME = time duration of beam wander calculation in seconds
3	N, M, N2 Format (3I4) N = Number of segments in designator path M = number of frequencies in power spectrum calculations N2 = Number of segments in seeker to target path. Not needed if IOPT = 1.

Card	Description
4	CN(I), I = 1, N Format (7E10.4) CN(I) = values of C_N^2 for laser designator path in (meter)$^{-2/3}$. One value required for each segment.
5	V1(I), I = 1, N Format (7E10.4) V1(I) = values of crosswind velocity for designator path in meters/second. One value required for each segment. Note: If IOPT = 1, no more cards are needed. If IOPT = 2, the following cards are required.
6	D1V, R1V Format (2E10.4) D1V = seeker aperture diameter in meters R1V = seeker range to target in meters
7	CN2(I), I = 1, M Format (7E10.4) CN2(I) = values of C_N^2 for seeker path in (meter)$^{-2/3}$. One value required for each segment.
8	V2(I), I = 1, M Format (7E10.4) V2(I) = values of crosswind velocity in seeker path in (meter)$^{-2/3}$. One value required for each segment.

2. Molecular Attenuation Model

The following list presents the data input needed for the molecular absorption model in use at the US Army Missile Research and Development Command (MIRADCOM). This information was extracted from the report by Miller et al. [3] which included additional input information. Spectroscopic data required are obtained from the AFGL tape which must be requested from the MIRCOM tape library for each run. The current serial number of the AFGL data tape used is S08997.

Card	Description
1	ALTI, ELVTN, DIST, IHR, ICM, IRL, IAL, ID Format (3F5.1, 4I1, 60X, I1) ALTI = initial altitude of path in kilometers ELVTN = angle of elevation in degrees of path from the horizontal

Card	Description

1 DIST = distance of path in kilometers

IHR = digit 1 to include high resolution molecular line absorption effects, 0 otherwise

ICM = digit 1 to include molecular continuum absorption effects, 0 otherwise

IRL = digit 1 to include Rayleigh scattering effects, 0 otherwise

IAL = not used; leave blank or 0

ID = digit 1 in column 80

2 V1, V2, CINC, FINC, SETBAK, BOUND, ACY, ID

Format (2F12.4, 2F10.4, 2F8.4, E10.3, 9X, I1)

V1 = starting frequency in cm^{-1}

V2 = end frequency in cm^{-1}

CINC = coarse increment in cm^{-1}

FINC = fine increment in cm^{-1}

SETBAK = wave number interval from line centers at which reversion to FINC should occur

BOUND = MAXIMUM half width of integration range

ACY = a measure of accuracy desired in terms of <u>magnitude</u> of <u>transmittance</u> (not a %)

ID = digit: 2 (in column 80)

3 NGDN, NADN, ICPN, IPRO, NP, DELV, SLIT, ID

Format (5I1, F8.5, F8.4, 58X, I1)

NGDN = number of atmospheric model or gas density versus altitude distribution
- = 0 (zero) for US 1962 Standard Atmosphere
- = 9 for user supplied atmospheric model

NADN = not used; leave blank or 0

ICPN = 0 for continuum calculation only at one wavenumber (the average value of VU and VL will be used ordinarily)
- = 1 for continuum calculation at every high-resolution wavenumber

IPRO = 0 for Lorentzian line profiles
- = 1 for collisionally-narrowed line profiles
- = 2 for generalized Voight profile

NP = not used; leave blank or 0

DELV = increment in cm^{-1} for frequencies at which transmission results are degraded

SLIT = half width of response function (triangular)
SLIT = 0.0 prevents convolution by the triangular slit

ID = digit; 3 (in column 80)

Card	Description
4 (One per altitude)	ALT(I), P(I), TEMP(I), AIR(I), H20(I), 03(I), G8(I), G9(I), G10(I), ID Format (F5.1, E10.4, F5.1, E10.4, E9.3, E9.3, 3E10.4, 1X, I1) ALT(I) = altitude in kilometers for ith data set for gases P(I) = pressure in mb at ALT(I) TEMP(I) = temperature in degrees Kelvin at ALT(I) AIR(I) = density of air in g/m^3 at ALT(I) H20(I) = density of water vapor in g/m^3 at ALT(I) 03(I) = density of ozone in g/m^3 at ALT(I) G8(I), G9(I), G10(I) = densities of additional optional gases in mol/cm^3 at ALT(I) ID = digit 4 (column 80)
5	DALT(I), DENS(I), ID Format (F5.1, E10.3, 64X I1) DALT(I) = altitude in kilometers for ith data set for aerosols DENS(I) = density of aerosols in $particles/cm^3$ at DALT(I) ID = digit 5 (column 80) A final type 5 carrying DALT( ) = 999.0 is required Note: Type 4 and 5 are needed only if the user wishes to insert his own density versus altitude models for (Type 4) gases and/or (Type 5) aerosols. Each type requires one card per altitude.

3. Aerosol Attenuation Model

Input data required for the aerosol attenuation model have changed somewhat from the format presented by Gomez et al. [4], but the calculations performed remain essentially the same. Additional size distribution options have been built into the model and the input data have been rearranged slightly. This model is used to provide the phase functions and aerosol attenuation coefficients for the First-Order Radiation Transport (FORT) model.

Card	Description
1	WAVE, DENS Format (2E12.6) WAVE = laser wavelength in micrometers DENS = particle density in particles/cc

Card	Description
2	IDSTP, NRADI, NCRDS, IT, MQRTE, MCRTE Format (6I5) IDSTP = 0, 1, ..., 7, size distribution option. See Card Type 3 for details. NRADI = number of different radii in size distribution. If IDSTP = 5, NRADI is used to give number of different ranges in size distribution. NCRDS = 0, for printed output only = 1, for printed and punched output IT = number of terms desired in the phase function expansion. MQRTE, MCRTE normally blank, but can be used to obtain additional printed output.
3	Data to be input here depend on the value of IDSTP given on Card Type 2.

If IDSTP=0 ⟷ "Arbitrary" distribution
F(I), R(I), I=1, NRADI
Format (2E20.10), number of input cards required = NRADI
F(I) = number of particles of radius R(I)

If IDSTP=1 ⟷ log normal distribution
RBAR, SIGMA
Format (2E20.10)
RBAR = mean radius
SIGMA = standard deviation

If IDSTP=2 ⟷ Wynn/Dawes exponential distribution
RLO, RHI, CUE, A, B
Format (5E12.6)
RLO = lower radius of distribution in micrometers
RHI = upper radius in micrometers
CUE, A, B are constants in distribution

If IDSTP=3 ⟷ Deirmendjian Model C.
No input needed; parameters are fixed.

If IDSTP=4 ⟷ Junge distribution
RLO, RHI, CUE, A
Format (4E10.4)
RLO = lower radius in micrometers
RHI = upper radius in micrometers
CUE, A are constants in distribution

If IDSTP=5 ⟷ Modified gamma distribution
RLO, RHI, RC, ALF, GAM, DENS, NRADI
Format (6E12.6, I3)
Number of cards required equals value of NRADI read in Card Type 2.
RLO = lower radius in micrometers
RHI = upper radius in micrometers
RC = mode radius in micrometers

Card	Description
3	ALF, GAM are constants in distribution DENS = particle density in this range NRADI = number of radii in this range
If IDSTP=6 ⟷	FOG model VIS Format (E20.10) VIS = visibility in kilometers
If IDSTP=7 ⟷	Hoidale dust model VIS Format (E12.6) VIS = visibility in kilometers
4	EM, CAY, EMM, CONC Format (4F10.6) EM = real part of particle index-of-refraction CAY = magnitude of imaginary part of particle index-of-refraction EMM = index-of-refraction of atmosphere usually 1.0 CONC is not used in this version: internally set to 1.0.

4. First-Order Radiation Transport (FORT) Model

The aerosol attenuation model described in the previous section is contained as subroutines in the FORT model. Data input for the FORT model consist of the three cards described in the following list of data followed by the input described in the previous section for the aerosol model. A complete Fortran listing is included at the end of this section.

Card	Description
1	LAMB, DIAM, THET, RANG, POWR, ZCLOUD Format (7E10.4) LAMB = laser wavelength in meters DIAM = transmitter aperture diameter in meters THET = laser beamspread angle in radians RANG = distance from transmitter to target in meters POWR = transmitter output power in meters ZCLOUD = distance from transmitter to aerosol cloud in meters
2	ZR, PHI, THETR, DR, RHO Format (5E10.4) ZR = range from target to receiver in meters PHI = viewing angle of receiver in radians THETR = field of view of receiver in radians DR = diameter of receiver aperture in meters RHO = reflectivity of target

Card	Description
3	NZ, NR, NM Format (3I4) NZ = number of segments in transmitter path NR = number of annular areas on the target NM = number of segments in transmitter path within field-of-view of receiver.

Card Type 4, etc., for this model begin with Card Type 1 described in previous section of this appendix.

FORTRAN LISTING OF TURBULENCE INDUCED BEAM WANDER MODEL

```
      PROGRAM MAIN(INPUT=65,OUTPUT=65,TAPE5=INPUT,TAPE6=OUTPUT)
C    MICOM POINTING JITTER PROGRAM
C    CALCULATES TURBULENCE INDUCED POINTING JITTER AND POWER SPECTRUM
C       FOR LASER TARGET DESIGNATOR AND TERMINAL HOMING SEEKER
C    *****REQUIRED INPUT DATA*****
C    IOPT   =  1, CALCULATIONS FOR DESIGNATOR PATH ONLY
C              2, CALCULATIONS FOR DESIGNATOR AND SEEKER PATHS
C   NRUNS   =  NO. OF CASES TO BE CALCULATED ( SEPARATE SET OF DATA IS
C              REQUIRED FOR EACH CASE)  .
C    LAMB   =  LASER WAVELENGTH IN METERS
C    DIAM   =  LASER TARGET DESIGNATOR APERTURE DIAMETER IN METERS
C    THET   =  LASER BEAMSPREAD ANGLE IN RADIANS
C    TDOT   =  LASER BEAM SLUE RATE IN RADIANS/SECOND
C    RANG   =  PROPAGATION RANGE FROM TARGET DESIGNATOR TO SPOT IN METERS
C    TIME   =  DURATION OF CALCULATION OR TEST  IN SECONDS
C    CN(I) =   VALUES OF REFRACTIVE INDEX STRUCTURE CONSTANT  (CN)**2
C              WITH ONE VALUE FOR EACH SEGMENT OF RANGE FROM LASER
C              DESIGNATOR TO TARGET (IN METERS**(-2/3))
C    V1(I) =   SET OF VALUES OF CROSSWIND VELOCITY CORRESPONDING TO
C              EACH SEGMENT OF RANGE FROM LASER DESIGNATOR TO TARGET(M/SEC)
C    M      =  NO. OF REQUENCIES FOR WHICH POINTING JITTER POWER SPECTRUM
C              IS TO BE CALCULATED
C    N      =  NO. OF SEGMENTS OF LENGTH DELZ FROM DESIGNATOR TO TARGET
C    D1V    =  DIAMETER OF SEEKER APERTURE IN METERS
C    R1V    =  RANGE FROM TARGET TO SEEKER IN METERS
C    CN2(I) =  VALUES OF REFRACTIVE INDEX STRUCTURE CONSTANT FOR EACH
C              SEGMENT OF RANGE FROM TARGET TO SEEKER (METERS**(-2/3))
C    V2(I) =   VALUES OF CROSSWIND VELOCITY FOR EACH SEGMENT OF RANGE
C              FROM TARGET TO SEEKER
C    N2     =  NO. OF SEGMENTS OF LENGTH DEL1V FROM  TARGET TO SEEKER
C    *******************************************************************
      DIMENSION CN(20),V1(20),F0(20),R0(20),FR(1025),PS(1025),V2(20)
      COMPLEX RAN(2048)
      COMMON/Z/ F0,R0,LAMB
      COMMON /XX/ CN2(20),D1V,R1V,N2
      COMMON /YY/ RAN
      COMMON /ZZ/ DRO
      REAL LAMB
      EXTERNAL DESUB,FALPH
   10 FORMAT(7E10.4)
   20 FORMAT(3I4)
      READ(5,20) IOPT,NRUNS
      DO 1000 LL = 1,NRUNS
      READ(5,10) LAMB,DIAM,THET,TDOT,RANG,TIME
      READ(5,20) N,M,N2
      READ(5,10) (CN(I),I = 1,N)
      READ(5,10) (V1(I),I = 1,N)
      IF(IOPT .EQ. 1) GO TO 145
      READ(5,10) D1V,R1V
      READ(5,10) (CN2(I),I=1,N2)
```

```
      READ(5,10) (V2(I),I = 1,N2)
   25 FORMAT(*  CALCULATION OF POWER SPECTRUM AND TURBULENCE INDUCED POI
     1NTING JITTER OF A LASER TARGET DESIGNATOR*//)
   30 FORMAT(*  CALCULATION OF POWER SPECTRUM AND TURBULENCE INDUCED POI
     1NTING JITTER OF A LASER TARGET DESIGNATOR AND SEEKER*//)
   40 FORMAT(*  LASER WAVELENGTH =*,E10.4,* METERS, DESIG. APERT. DIAM=*
     1,F10.6,* METERS, BEAMSPREAD ANGLE =*,F10.6,* RADIANS*/)
   45 FORMAT(* SEEKER APERT. DIAM. =*,F10.6,*METERS, RANGE FROM TARGET T
     1O SEEKER =*,F10.2,*METERS*/)
   50 FORMAT(*  BEAM SLUE RATE =*,F10.6,*RAD/SEC, DESIGNATION RANGE =*,F
     110.2,* METERS*/)
   55 FORMAT(*  DURATION OF TEST IS *,F10.4,* SECONDS*/)
   60 FORMAT(*  NO. OF SEGMENTS IN DESIGNATOR PATH =*,I3/)
   65 FORMAT(*  NO. OF SEGMENTS IN SEEKER PATH = *,I3/)
   70 FORMAT(*  NO. OF FREQUENCIES FOR WHICH POWER SPECTRUM IS TO BE CAL
     1CULATED =*,I4//)
   80 FORMAT(*  VALUES OF REFRACTIVE INDEX STRUCTURE CONSTANT AND WIND S
     1PEED IN DESIGNATOR PATH*/)
   85 FORMAT(*  VALUES OF REFRACTIVE INDEX STRUCTURE CONSTANT AND WIND S
     1PEED IN SEEKER PATH*/)
   90 FORMAT(*  SEGMENT NO. = *,I2,*, REF. INDEX STRUCTURE CONST. =*,E12
     1.6,* (METER)2/3   , WIND SPEED =*,F10.4,* METER/SEC*/)
  100 FORMAT(*  VALUES OF FREQUENCY FOR WHICH  POWER SPECTRUM CALCULATIO
     1NS ARE TO BE MADE*/)
  110 FORMAT(5F16.6)
  115 FORMAT(10E12.4)
  120 FORMAT(*  FOR FREQUENCY OF *,F10.4,* HERTZ, THE CALCULATED POWER S
     1PECTRUM IS *E12.4,*, THE VARIANCE IS*E12.4/)
  130 FORMAT(1H0)
  140 FORMAT(1H1)
  145 CONTINUE
      WRITE(6,140)
      IF(IOPT .EQ. 1) WRITE( 6,25)
      IF(IOPT .EQ. 2) WRITE( 6,30)
      WRITE(6,40)  LAMB,DIAM,THET
      IF(IOPT .EQ. 2) WRITE( 6,45) D1V,R1V
      WRITE(6,50)  TDOT,RANG
      WRITE(6,55) TIME
      WRITE(6,60) N
      IF(IOPT .EQ. 2) WRITE(6,65) N2
      WRITE(6,70)  M
      WRITE(6,80)
      DO 150 I = 1,N
  150 WRITE(6,90) I,CN(I),V1(I)
      WRITE(6,130)
      IF(IOPT .EQ. 1) GO TO 156
      WRITE(6,85)
      DO 155 I = 1,N2
  155 WRITE(6,90) I,CN2(I),V2(I)
      WRITE(6,130)
C  COMPUTATION OF TIME, FREQUENCY AND SPATIAL INCREMENTS
  156 CONTINUE
      DELT = TIME/M  $DELF = 1./TIME
      DELZ = RANG/FLOAT(N)   $DEL1V = R1V/FLOAT(N2)
```

```
      MM = M + M  $M1 = M + 1  $MM1 = MM + 1  $MM2 = MM + 2
      MSQ = SQRT(FLOAT(MM))
      DO 160 I = 2,M1
      FR(I) = (I - 1)*DELF
  160 CONTINUE
      R2 = DIAM/THET
      R = RANG + R2
      D2 = DIAM + THET*RANG
C  COMPUTATION OF EFFECTIVE WIND VELOCITY, COHERENCE LENGTH AND
C  NORMALIZATION FREQUENCY FOR EACH SEGMENT OF PATH FROM LASER
C  DESIGNATOR TO TARGET
      ZI = R2
      Z1 = DELZ/2.
      ROT = 0.0
      DEL = 0.0
      DO 200 I = 1,N
      ZI = ZI + Z1
      Z1 = DELZ
      VEI = V1(I) + TDOT*(ZI - R2)
      RO(I) = (16.7*DELZ*CN(I)*(ZI/R   )**1.66667/(LAMB*LAMB))
      FO(I) =  VEI /(3.14159*D2*ZI/R)
      ROT = ROT + RO(I)
      DEL = DEL + DELZ*CN(I)*(RANG - ZI)/RANG
      RO(I) = RO(I)**(-.6)
  200 CONTINUE
      ROT = ROT**(-.6)
C  COMPUTATION OF BEAM SPREAD ANGLE DUE TO TURBULENCE AND DIFFRACTION
C  COMPUTATION OF SPOT DIAMETER ON TARGET
      DRO = DIAM/ROT
      CALL IGRAT(0.,1.,.01,1,DESUB,RDRO)
      RDRO = 1.0/(SQRT(5.092958*(DRO)**2*RDRO))
      THET12 = 1.128*LAMB/ROT*RDRO
      DTHET = SQRT(THET12**2 + THET**2)
      D22= DIAM + DTHET*RANG
      WRITE(6,210) D2,R2,R,DEL,D22
      WRITE(6,240)
      WRITE(6,110) (RO(I),I=1,N)
      WRITE(6,130)
      WRITE(6,245)
      WRITE(6,110) (FO(I),I=1,N)
  210 FORMAT(*  SPOT DIAM. =*,E12.6,*,  R2 =*,F10.4,*, R1+R2 =*,F10.4,*,
     1  DEL = *,E12.6/,* TURB. INDUCED SPOT DIAM. = *E12.6/)
  240 FORMAT(*  VALUES OF RO(I), I = 1, N)*/)
  245 FORMAT(*  VALUES OF FO(I), I = 1, N)*/)
C  COMPUTATION OF ANGLE OF ARRIVAL POWER SPECTRUM OF LASER DESIGNATOR
      F2 = 0.
      PS(1) = 0.
      DO 300 J = 2,M1
      F = FR(J)
      F1 =0.
      CALL SPECT(F,F1,D2,N)
      PS(J) = F1
      IF(IOPT .EQ. 1)PS(J) = F1*(D2/DIAM)**2
      F2 = F2 + PS(J)*DELF
```

```
      IF(J .LT. M)GO TO 300
      IF(IOPT .EQ. 1)WRITE(6,120)F,PS(J),F2
  300 CONTINUE
      IF(IOPT .EQ. 1) GO TO 306
C  COMPUTATION OF EFFECTIVE WIND VELOCITY, COHERENCE LENGTH AND
C  NORMALIZATION FREQUENCY  FOR EACH SEGMENT OF PATH FROM
C  TARGET TO SEEKER
      ZI = 0. $Z1 = DEL1V/2.
      DO 220 I = 1,N2
      ZI = ZI + Z1
      Z1 = DEL1V
      VEI = V2(I) + TDOT*(RANG - ZI)
      RO(I) = (16.7*DEL1V*CN2(I)*(ZI/R1V)**1.66667/(LAMB*LAMB))**(-.6)
      FO(I) = VEI/(3.14159*D1V*ZI/R1V)
  220 CONTINUE
      WRITE(6,130)
      WRITE(6,2400)
      WRITE(6,110) (RO(I),I=1,N2)
      WRITE(6,130)
      WRITE(6,2450)
      WRITE(6,110) (FO(I),I=1,N2)
 2400 FORMAT(*  VALUES OF RO(I), I = 1, N2)*/)
 2450 FORMAT(*  VALUES OF FO(I), I = 1, N2)*/)
C  COMPUTATION OF TURBULENCE INDUCED POINTING JITTER POWER SPECTRUM
C  FROM TARGET SPOT TO LASER SEEKER.  COMPUTATION OF TOTAL POWER
C  SPECTRUM FROM LASER DESIGNATOR TO SEEKER AND POWER SPECTRUM VARIANCE
      CALL THETO(THETAO,FALPH)
      WRITE(6,140)
      F2 = 0.
      DO 305 J = 2,M1
      F = FR(J)
      F1 = 0.
      CALL SPECT(F,F1,D1V,N2)
      PS(J) = PS(J) + F1/(1.+(D2/(R1V*THETAO))**2)
      PS(J) = PS(J)*(D2/D1V)**2
      F2 = F2 + PS(J)*DELF
      IF(J .LT. M)GO TO 305
      WRITE(6,120) F,PS(J),F2
  305 CONTINUE
  306 CONTINUE
      WRITE(6,310)
      WRITE(6,115) (PS(J),J = 1,M1)
      WRITE(6,130)
  310 FORMAT(* CALCULATED POWER SPECTRUM VS. FREQUENCY*/)
      DO 1000 L = 1,2
      WRITE(6,140)
      WRITE(6,320) L
  320 FORMAT(*  /////  OUTPUT  FOR  DIRECTION *,I2,* /////*//)
C  GENERATION OF RANDOM SEQUENCE HAVING SAME POWER SPECTRUM  VARIANCE
C  AS INDUCED BY TURBULENCE.  ADD SYMMETRIC TERMS FOR NEGATIVE
C  FREQUENCIES.  COMPUTE MEAN AND VARIANCE OF RANDOM ARRAY
      RAN(1) = (0.,0.)
      DO 350 I = 2,M1
      MMM = MM2 - I
```

```
      RAN(I) = DNRMAL(0.,1.0)*SQRT(PS(I)/DELT)
      RAN(MMM) = RAN(I)
  350 CONTINUE
      WRITE(6,130)
C  COMPUTE AND WRITE MEAN AND VARIANCE OF RANDOM ARRAY
      WRITE(6,360)
      CALL MEANVAR(1,M)
C  FAST FOURIER TRANSFORM RANDOM ARRAY
      CALL FFT(RAN,MM,+1)
      DO 450 I = 1,MM
      RAN(I) = RAN(I)/MSQ
  450 CONTINUE
C  COMPUTE AND WRITE MEAN AND VARIANCE OF TIME SEQUENCE.
      WRITE(6,480)
      CALL MEANVAR(M1,MM)
      WRITE(6,130)
C  WRITE TRANSFORMED ARRAY VALUES CORRESPONDING TO TIME VALUES
C  OF POINTING JITTER FOR ONE DIRECTION.
      WRITE(6,130)
      WRITE(6,460) DELT
      WRITE(6,115) (REAL(RAN(I)),I = M1,MM)
 1000 CONTINUE
  360 FORMAT(*  MEAN AND VARIANCE OF RANDOM ARRAY*//)
  460 FORMAT(*  VALUES OF POINTING JITTER AT *,F10.6,* SEC INTERVALS BEG
     1INNING AT T = 0*/)
  470 FORMAT(*  RANDOM VALUES VS. FREQUENCY AT*,F10.4,* HZ INTERVALS*/)
  480 FORMAT(*  MEAN AND VARIANCE OF TIME SEQUENCE*//)
      END
      SUBROUTINE SPECT(F,F1,D2,N)
      COMMON/Z/ FO(20),RO(20),LAMB
      REAL LAMB
      FACT = 1.32E-2*(LAMB/D2)**2
      F1 =0.
      DO 250 I = 1,N
      IF(F .LE..332*FO(I)) G =1.
      IF(F .GT..332*FO(I)) G =1.12 - .361*F/FO(I)
      IF(F .GE.3.10*FO(I)) G =0.
      F1 = F1 + FACT*((D2/RO(I))**5/(F*F*FO(I)))**.33333*G
  250 CONTINUE
      RETURN
      END
      SUBROUTINE DESUB(X,Y,NDEQ)
      COMMON /ZZ/ DRO
    1 Y=X*((ACOS(X)-X*(1.-X**2)**.5)*EXP(-3.44*(DRO*X)**1.6667*(1.-X**0.
     13333)))
      RETURN
      END
      SUBROUTINE THETO(THETAO,FALPH)
      COMMON /XX/ CN2(20),D1V,R1V,N2
      DEL1V = R1V/FLOAT(N2)
C     CALCULATE D1INF
      D1INF=0.  $S1=DEL1V/2.  $S =0.
      D1V3 = (D1V)**(-.3333)
      DO 20 I = 1,N2
```

```
      S = S + S1
      D1INF=DEL1V*CN2(I)*((S/R1V)**1.6667) + D1INF
   20 S1 = DEL1V
      D1INF = 0.5*11.97*D1V3*D1INF
C   INITIAL ESTIMATE FOR THETA0
      WRITE(6,35) D1INF
      THETA0 = 1.E-4
   25 CONTINUE
      XI1=0.  $D1THE=0.  $S = 0.
      S1 = DEL1V/2.
      DO 30 I = 1,N2
      S = S + S1
      XI1 = THETA0*(R1V-S)/D1V
      D1THE = DEL1V*CN2(I)*((S/R1V)**1.6667)*FALPH(XI1) + D1THE
   30 S1 = DEL1V
      D1THE = D1THE*D1V3
      IF(ABS((D1INF-D1THE)/D1INF) .LT. .001) GO TO 40
      THETA0 = THETA0*(1. + .5*(D1INF-D1THE)/D1INF)
      WRITE(6,35) THETA0,D1THE
      GO TO 25
   35 FORMAT(2E16.8)
   40 CONTINUE
      WRITE(6,35) D1THE
      RETURN
      END
      FUNCTION FALPH(XI1)
      DIMENSION A(8)
      DATA (A(I),I=1,8)/1.98714,10.3433,-5.90301,1.83619,-0.301442,
     1 2.51509E-2,-9.75229E-4,1.35618E-5/
      IF(XI1 .GE. .5623) GO TO 10
      FALPH = 10.66*((XI1)**2)
      GO TO 40
   10 IF(XI1 .GT.31.62) GO TO 20
      FALPH = 0.0
      DO 15 I = 1,8
   15 FALPH = A(I)*((XI1)**(I-1)) + FALPH
      GO TO 40
   20 IF(XI1 .GT.1000.) GO TO 30
      FALPH = 7.8*((XI1)**.06)
      GO TO 40
   30 FALPH = 11.97
   40 RETURN
      END
      SUBROUTINE MEANVAR(N1,N2)
      COMPLEX RAN(2048)
      COMMON /YY/ RAN
      REAL MEAN1,MEAN2
      MEAN1=MEAN2=VAR1=VAR2=0.
      DO 400 I = N1,N2
      MEAN1 = REAL(RAN(I)) + MEAN1
      MEAN2 = AIMAG(RAN(I)) + MEAN2
      VAR1 = (REAL(RAN(I)))**2 + VAR1
      VAR2 = (AIMAG(RAN(I)))**2 + VAR2
  400 CONTINUE
```

```
      MEAN1 = MEAN1/FLOAT(N2 - N1)
      MEAN2 = MEAN2/FLOAT(N2 - N1)
      VAR1 = VAR1/FLOAT(N2 - N1)
      VAR2 = VAR2/FLOAT(N2 - N1)
      WRITE(6,700)MEAN1, MEAN2
      WRITE(6,800)VAR1,VAR2
      RETURN
  700 FORMAT(* MEAN OF REAL PART =*,E12.6,*, MEAN OF IMAG PART =*E12.6/)
  800 FORMAT(* VAR. OF REAL PART =*,E12.6,*, VAR. OF IMAG PART =*E12.6/)
      END
```

```
      PROGRAM FORT(INPUT=65,OUTPUT=65,TAPE5=INPUT,TAPE6=OUTPUT)
C     PROGRAM TO COMPUTE FIRST ORDER RADIATION TRANSPORT FROM A LASER
C     TRANSMITTER TO A TARGET AND THE REFLECTED AND SCATTERED RADIATION
C     TO A RECEIVER VIEWING THE TARGET
C    *****REQUIRED INPUT DATA*****
C    LAMB    =  LASER WAVELENGTH IN MICROMETERS
C    DIAM    =  TRANSMITTER APERTURE DIAMETER IN METERS
C    THET    =  LASER BEAMSPREAD ANGLE IN RADIANS
C    RANG    =  PROPAGATION RANGE FROM  TRANSMITTER TO SPOT IN METERS
C    POWR    =  TRANSMITTER OUTPUT POWER IN WATTS
C    ZCLOUD  =  DISTANCE FROM TRANSMITTER TO CLOUD IN METERS
C    ZR      =  RANGE FROM TARGET TO RECEIVER IN METERS
C    PHI     =  VIEWING ANGLE OF RECEIVER IN RADIANS
C    THETR   =  FIELD OF VIEW OF RECEIVER IN RADIANS
C    DR      =  RECEIVER DIAMETER IN METERS
C    RHO     =  REFLECTIVITY OF TARGET
C    NZ      =  NO. OF SEGMENTS OF LENGTH DELZ FROM TRANSMITTER TO TARGET
C    NR      =  NUMBER OF ANNULAR AREAS IN THE TARGET SPOT
C    NM      =  NUMBER OF SEGMENTS OF TRANSMITTER PATH SEEN BY RECEIVER
C    **************************************************************
      DIMENSION ZN(20),RN(20),P(100),C(100),AREA(20),PWR(20),AINT(20)
      DIMENSION GAM(20),ZL(20)
      COMMON/BK2 /              C,  ALBDO,LLLL,NCRDS,IT,ITT,NRADI
      REAL LAMB,KEXT
   10 FORMAT(7E10.4)
   20 FORMAT(3I4)
      READ(5,10) LAMB,DIAM,THET,RANG,POWR,ZCLOUD
      READ(5,10) ZR,PHI,THETR,DR,RHO
      READ(5,20) NZ,NR,NM
   40 FORMAT(*  LASER WAVELENGTH =*,F10.4,* MICRON, DESIG. APERT. DIAM=*
     1,F10.6,* METERS, BEAMSPREAD ANGLE =*,F10.6,* RADIANS*/)
   50 FORMAT(*  DESIGNATOR RANGE =*,F10.2,* METERS*/,*  DESIGNATOR POWER
     1 =*,F10.3,* WATTS*/,*  DISTANCE TO CLOUD =*,F10.2,* METERS*/)
  55  FORMAT(*  RECEIVER RANGE =*,F10.2,* METERS,  REC. FOV =*,F10.5,* R
     1ADIANS*/,*  RECEIVER VIEWING ANGLE =*,F10.4,* RADIANS, RECEIVER DI
     2AM. =*,F10.6,* METERS*/,*  TARGET REFLECTIVITY =*,F10.6/)
   60 FORMAT(*  NO. OF SEGMENTS IN DESIGNATOR PATH =*,I3/*  NO. OF ANNUL
     1AR ELEMENTS IN SPOT =*,I3/,*  NO. OF SCATTERING SEGMENTS =*,I3/)
   70 FORMAT(8F16.8)
  115 FORMAT(10E12.4)
  130 FORMAT(1H0)
  140 FORMAT(1H1)
      PI=3.141592653589
      WRITE(6,140)
      WRITE(6,40)  LAMB,DIAM,THET
      WRITE(6,50)  RANG,POWR,ZCLOUD
      WRITE(6,55)ZR,THETR,PHI,DR,RHO
      WRITE(6,60) NZ,NR,NM
C    COMPUTATION OF SPATIAL INCREMENTS
C   COMPUTATION OF SPOT DIAMETER ON TARGET
      IT = NR*NZ
      IOUT = IT - 2
      ZD = DIAM/THET
```

```
      ZC = ZD + ZCLOUD
      ZT = RANG + ZD
      DT = DIAM + THET*RANG
      ZI = ZC
      DELZ = (ZT - ZC)/FLOAT(NZ)
      DELR = DT/FLOAT(NR)
      Z1 = DELZ/2.
      DO 200 I = 1,NZ
      ZI = ZI + Z1
      Z1 = DELZ
      ZN(I) = ZI
  200 CONTINUE
      WRITE(6,210) DT,ZD,ZT
  210 FORMAT(*  SPOT DIAM. =*,E12.6,*,  ZD =*,F10.4,*, ZT = *,F10.4/)
      WRITE(6,215)
      WRITE(6,70) (ZN(I),I = 1,NZ)
  215 FORMAT(*   VALUES OF (ZN(I),I = 1,NZ) */)
C  COMPUTATION OF RADIUS TO ANNULAR ELEMENTS ON TARGET
C  COMPUTATION OF AREA OF ANNULAR ELEMENTS ON TARGET
      RI = 0.
      AI = 0.
      R1 = DELR/2.
      DO 220 I = 1,NR
      PWR(I) = 0.
      A1 = PI*((DELR*FLOAT(I))**2)
      AREA(I) = A1 - AI
      AI = A1
      RI = RI + R1
      R1 = DELR
      RN(I) = RI
  220 CONTINUE
      WRITE(6,130)
      WRITE(6,225)
  225 FORMAT(*   VALUES OF ((RN(I),AREA(I)), I = 1,NR) */)
      WRITE(6,70) ((RN(I),AREA(I)),I = 1,NR)
      DO 230 J = 1,NZ
      DO 230 I = 1,NR
      ANG = ATAN(RN(I)/(ZT - ZN(J)))
      L = NR*(J - 1) +I
  230 C(L) = COS(ANG)
      KKK = 1
      CALL AGAUSS(P,KEXT,KKK)
      WRITE(6,130)
C     WRITE(6,235)
C 235 FORMAT(*   VALUES OF ((C(I), P(I)), I = 1,IT) */)
C     WRITE(6,70) (C(I),P(I),C(I+1),P(I+1),C(I+2),P(I+2),C(I+3),P(I+3),
C    1I=1,IOUT,4)
      DO 240 J = 1,NZ
      ZTZN = ZT - ZN(J)
      POWFAC = POWR*EXP(-KEXT*(ZN(J)-ZC))*(1.-EXP(-KEXT*DELZ))
     1*EXP(-KEXT*ZTZN)*ALBDO
      DO 240 I = 1,NR
      L = NR*(J - 1) +I
      PWR(J) = PWR(J) + POWFAC*P(L)*AREA(I)/(ZTZN**2 + RN(I)**2)
```

```
  240 CONTINUE
      WRITE(6,130)
      WRITE(6,245)
  245 FORMAT(*   POWER AND AVERAGE INTENSITY IN ANNULAR AREAS */)
      TPOW = 0.0
      POWER = POWR*EXP(-KEXT*(RANG - ZCLOUD))
      DO 250 I = 1,NR
      TPOW = TPOW + PWR(I)
      AINT(I) = PWR(I)/AREA(I)
 250  CONTINUE
      WRITE(6,70) ((PWR(I),AINT(I)),I=1,NR)
      WRITE(6,130)
      WRITE(6,255) POWER,TPOW
  255 FORMAT(*   DIRECT POWER TO TARGET =*,F16.8,* WATTS*/,*   SCATTERED
     1 POWER TO TARGET =*F16.8,* WATTS*/)
      DO 260 I = 1,NR
      AINT(I) = AINT(I) + 2.*POWER/(PI*DT*DT)*EXP(-2.*RN(I)*RN(I)/(DT*DT
     1))
  260 CONTINUE
      WRITE(6,265)
      WRITE(6,70) (AINT(I),I=1,NR)
  265 FORMAT(*   TOTAL INTENSITY = DIRECT + SCATTERED VS. RN(I)*/)
      WRITE(6,130)
      THETR2 = THETR/2.
      GAMA = PI - THETR2 - PHI
      AR = PI*DR*DR/4.
      ZM = ZR*SIN(THETR2)/SIN(GAMA)
      IF(ZM .GT. RANG) ZM = RANG
      ZS = RANG - ZM
      IF(ZS .LT. ZCLOUD) ZS = ZCLOUD
      IT = NM
      IOUT = IT - 3
      IF(IOUT .LT. 1) IOUT = 1
      DELZ = (RANG - ZS)/FLOAT(NM)
      WRITE(6,267) GAMA,ZM,ZS
  267 FORMAT(*  GAMA =*,F10.5,*, ZM =*,F10.3,*, ZS =*,F10.3/)
      ZI = ZS
      Z1 = DELZ/2.
      DO 270 I = 1,NM
      ZI = ZI + Z1
      Z1 = DELZ
      ZN(I) = ZI
      ZL(I) = SQRT(ZR**2 +(RANG-ZN(I))**2 - 2.*ZR*(RANG-ZN(I))*COS(PHI))
      TETAR = ASIN((RANG - ZN(I))*SIN(PHI)/ZL(I))
      GAM(I) = PI - TETAR - PHI
      C(I) = COS(GAM(I))
  270 CONTINUE
      WRITE(6,275)
  275 FORMAT(*  VALUES OF ((ZN(I),ZL(I)),I = 1,NM)*,/)
      WRITE(6,70) ((ZN(I),ZL(I)),I=1,NM)
      WRITE(6,130)
      KKK = 2
      CALL AGAUSS(P,KEXT,KKK)
      PWRSR = 0.0
```

```
      DO 280 J = 1,NM
      ZLJ = ZL(J)
      IF(ZCLOUD .GT. .001 .AND. ZR*COS(PHI) .GT. (RANG-ZCLOUD))
     1ZLJ = (ZN(J) - ZCLOUD)/COS(PI - GAM(J))
      PWRSR = PWRSR + POWR*EXP(-KEXT*(ZN(J)-ZC))*(1.-EXP(-KEXT*DELZ))*
     1ALBDO*P(J)*AR/(ZL(J)**2)*EXP(-KEXT*(ZLJ))
  280 CONTINUE
      ZRCL = ZR
      IF(ZCLOUD .GT. .001 .AND. ZR*COS(PHI) .GT. (RANG-ZCLOUD))
     1ZRCL = (RANG - ZCLOUD)/COS(PHI)
      PWRTR = (POWER + TPOW)*RHO*COS(PHI)*AR/(ZR*ZR*PI)*EXP(-KEXT*ZRCL)
      WRITE(6,285) PWRSR,PWRTR
      WRITE(6,130)
  285 FORMAT(*  POWER SCATTERED FROM BEAM TO RECEIVER =*,E16.8,* WATTS*/
     1,*  POWER REFLECTED FROM TARGET TO RECEIVER =*,E16.8,* WATTS*/)
      END
      SUBROUTINE AGAUSS(PSUM,QTSUM,KKK)
      DIMENSION F( 500),R( 500),FSUMI(10),C(100),P(100),PSUM(100)
      COMMON/BK2 /              C,  ALBDO,LLLL,NCRDS,IT,ITT,NRADI
    1 FORMAT(6I5,49X,I1)
    2 FORMAT(4F10.6)
    3 FORMAT(24X,2(E20.10))
    4 FORMAT(2E20.10)
    5 FORMAT(6E12.6,I3)
    6 FORMAT(4E10.4)
    7 FORMAT(1H ,100H******AEROSOL DISTRIBUTION TYPE IS UNDEFINED*******
     *EXECUTION CONTINUING ASSUMING NO AEROSOL MATERIAL)
    8 FORMAT(1H ,41H  DISTRIBUTION  WAVELENGTH     REFRACTIVE,13X,12HC E
     *XTINCTION,13X,12HC SCATTERING,16X,5HALBDO/1H ,6X,4HTYPE,6X,9H(MICR
     *ONS),8X,5HINDEX,16X,12H(SQ MICRONS),13X,12H(SQ MICRONS)/1H ,I9,4X
     *,F11.4,F10.4,2H(1,F7.4,2HI),3E25.14)
    9 FORMAT(1H0,4(5H    MU,8X,17HPHASE FUNCTION    )/1H )
   10 FORMAT(1H ,4(F13.9,E17.10))
   11 FORMAT(1H0,65X,14HPHASE FUNCTION/1H )
   12 FORMAT(1H ,5X,1HL,20X,16HL-TH COEFFICIENT,23X,14HRMS  DEVIATION/1H
     * )
   13 FORMAT(1H ,8H    MU  ,4(30H    ORIGINAL        EXPANDED    )/1H )
   14 FORMAT(1H ,F8.5,8E15.8)
   15 FORMAT(1H ,/////24H AEROSOL PARAMETERS ARE )
   16 FORMAT(1H+,24X,6HRBAR= ,E20.10,15X,7HSIGMA= ,E20.10/)
   17 FORMAT(1H+,24X,5HRLO= ,E10.4,1X,5HRHI= ,E10.4,1X,5HCUE= ,E10.4,1X,
     *3HA= ,E10.4,1X,3HB= ,E10.4/)
   18 FORMAT(1H+,24X,5HRLO= ,E10.4,1X,5HRHI= ,E10.4,1X,5HCUE= ,E10.4,1X,
     *3HA= ,E10.4,1X,4HVIS= ,E10.4/)
   19 FORMAT(1H+,24X,5HRLO= ,E10.4,1X,5HRHI= ,E10.4,1X,4HRC= ,E10.4,1X,5
     *HALF= ,E10.4,1X,5HGAM= ,E10.4,7H NRADI=,I3,4H JZ=,I3/)
   20 FORMAT(1H+,24X,3HA= ,F4.1,1X,7HNRADI= ,I4,1X,5HGAM= ,F4.1,1X,5HVIS
     *= ,E20.10/)
   21 FORMAT(1H+,24X,40H  RADIUS  (MICRONS)   RELATIVE  DENSITY /)
   22 FORMAT(* INDX=*,I3,* M= *,F10.6,* K = -*,F10.6,*I. EMM=*,F8.6,*
     *CONCENTRATION = *,F 10.6 )
   23 FORMAT(* THIS IS A MIXED CASE---SUBSEQUENT REFRACTIVE INDEX PRINT-
     *OUTS ARE NOT GENERALLY VALID*)
   24 FORMAT(1H ,24X,* MIE SIZE PARAMETER RANGE
```

```
     *,F8.4/)
   25 FORMAT(2(F15.5,5X),3(E20.6,5X))
   26 FORMAT(1H ,//4X,16HRADIUS (MICRONS),4X,14HSIZE PARAMETER,13X,7HQ (
     *EXT) ,17X,7HQ (SCA), 19X,9HQ (RADAR))
   27 FORMAT(/* NORMALIZATION FACTOR FOR SIZE DISTRIBUTION = *,E14.7/)
   28 FORMAT(/* K(EXT) = *,E13.7,*  K(SCA) = *,E13.7,*  K(RAD) = *,E13.7
     * /)
   29 FORMAT(/* WAVENUMBER = *,E15.7,* CM-1*,5X,*DENSITY = *,E15.7, *PAR
     *TICLES PER CM-3*/)
C
C     END PRELIMINARIES
C
      IF(KKK .GT. 1) GO TO 52
      READ(5,5)WAVE,DENS
      IF(DENS.EQ.0.0)DENS=1.0
      GNU=1.0E+04/WAVE
      NRANGE=1
      READ(5,1)IDSTP,NRADI,NCROS
      IF(IDSTP.EQ.5)NRANGE=NRADI
      ITMM=IT-1
      PI=3.1415926535898
      WRITE(6,15)
      IF(IDSTP.NE.0)GO TO(34,36,38,40,43,47,40,51),IDSTP
      READ(5,4)(F(J),R(J),J=1,NRADI)
      WRITE(6,21)
      WRITE(6,3)(R(J),F(J),J=1,NRADI)
      FSUM=0.0
      DO 33 J=1,NRADI
   33 FSUM=FSUM+F(J)
      GO TO 49
   34 READ(5,4)RBAR,SIGMA
      WRITE(6,16)RBAR,SIGMA
      RHI=RBAR* EXP(3.0*SIGMA)
      RLO=RBAR* EXP(-3.0*SIGMA)
      RADS= FLOAT(NRADI-1)
      DELRD=(RHI-RLO)/RADS
      FSUM=0.0
      DEN=2.0*SIGMA*SIGMA
      DO 35 J=1,NRADI
      RJ=J-1
      R(J)=RLO+RJ*DELRD
      GNUM=ALOG(R(J)/RBAR)
      F(J)= EXP(-GNUM*GNUM/DEN)*RBAR/R(J)
   35 FSUM=FSUM+F(J)
      GO TO 49
   36 READ(5,5)RLO,RHI,CUE,A,B
      WRITE(6,17)RLO,RHI,CUE,A,B
      RADS= FLOAT(NRADI-1)
      DELRD=(RHI-RLO)/RADS
      FSUM=0.0
      DO 37 J=1,NRADI
      RJ=J-1
      R(J)=RLO+RJ*DELRD
      F(J)=CUE*A* EXP(-A*R(J))+(1.0     -CUE)*B* EXP(-B*R(J))
```

```
37 FSUM=FSUM+F(J)
   GO TO 49
38 FSUM=0.0
   DENS=1.378E+04
   DELRD=0.02
   DO 39 J=1,NRADI
   RJ=J-1
   R(J)=0.02     +RJ*DELRD
   IF(J.LT.5)F(J)=450.2
   IF(J.GE.5)F(J)=2.251     *DELRD*R(J)**(-4.0)
39 FSUM=FSUM+F(J)
   GO TO 49
40 IF(IDSTP.EQ.4)  GO TO 41
   READ(5,5) VIS
   RLO=0.1
   RHI=15.0
   CUE=30.0
   A=4.0
   NRADI=300
   DENS=1.1     *10.0     **(+5.0     -ALOG10(VIS))
41 IF(IDSTP.EQ.4)  READ(5,6) RLO,RHI,CUE,A
   WRITE(6,18)RLO,RHI,CUE,A,VIS
   FSUM=0.0
   RADS= FLOAT(NRADI-1)
   DELRD=(RHI-RLO)/RADS
   DO42 J=1,NRADI
   RJ=J-1
   R(J)=RLO+RJ*DELRD
   F(J)=CUE*R(J)**(-A)
   IF(IDSTP.EQ.7.AND.J.LE.3)  F(J)=1.0E+05
42 FSUM=FSUM+F(J)
   GO TO 49
43 JZ=0
   FSUM=0.0
   DO 45 ISZ=1,NRANGE
   READ(5,5)RLO,RHI,RC,ALF,GAM,DENS,NRADI
   WRITE(6,19)RLO,RHI,RC,ALF,GAM,NRADI,JZ
   FSUMI(ISZ)=0.0
   DELRD=(RHI-RLO)/ FLOAT(NRADI-1)
   B=ALF/(GAM*RC**GAM)
   DO 44 J=1,NRADI
   R(J+JZ)=RLO+DELRD* FLOAT(J-1)
   IF(J.EQ.1)XMN=2.0     *PI*R(J+JZ)/(WAVE)
   IF(J.EQ.NRADI)XMX=2.0     *PI*R(J+JZ)/(WAVE)
   F(J+JZ)=( EXP(-B*R(J+JZ)**GAM)*R(J+JZ)**ALF)*DELRD
44 FSUMI(ISZ)=FSUMI(ISZ)+F(J+JZ)
   DELRD=DELRD*2.0     *PI/(WAVE)
   WRITE(6,24)XMN,DELRD,XMX
45 JZ=NRADI+JZ
   DO 46 JN=1,NRANGE
46 FSUM=FSUM+FSUMI(JN)
   NRADI=JZ
   GO TO 49
47 READ(5,4) VIS
```

```
      FSUM=0.0
      DELLR=0.02
      A=500.
      NRADI=280
      GAM=3.0
      WRITE(6,20)A,NRADI,GAM,VIS
      PWR=-2.0     *GAM/3.0
      R(1)= (VIS-0.04      )/0.31
      F(1)=A*R(1)**PWR
      DO48 I=2,NRADI
      EXPO=ALOG(R(I-1))+DELLR
      R(I)= EXP(EXPO)
      F(I)=A*R(I)**PWR
   48 FSUM=FSUM+F(I)
   49 DO 50 J=1,NRADI
   50 F(J)=F(J)/FSUM
      WRITE(6,27)FSUM
      GO TO 52
   51 WRITE(6,7)
      GO TO 61
   52 QTSUM=0.0
      QSSUM=0.0
      QRSUM=0.0
      DO 53 J=1,IT
   53 PSUM(J)=0.0
      IF(KKK .GT. 1) GO TO 100
C     READ(5,1)NINDX
C     DO 57 NK=1,NINDX
      READ(5,2)EM,CAY,EMM,CONC
      CONC = 1.0
      WRITE(6,22)NK,EM,CAY,EMM,CONC
      CAY=CAY/EM
      IF(MQRTE.EQ.12345)WRITE(6,26)
  100 CONTINUE
      DO 56 L=1,NRADI
      ALPHA=2.0     *PI*EMM *R(L)/WAVE
      CALL FMIEG2(EM,CAY,ALPHA,QT,QS,QR,P,MQRTE,KKK)
      IF(MQRTE.EQ.12345) WRITE(6,25)R(L),ALPHA,QT,QS,QR
      DO 54 J=1,IT
      PSUM(J)=PSUM(J)+P(J)*F(L)*CONC
   54 CONTINUE
   55 QTSUM=QTSUM+R(L)*R(L)*QT*F(L)*CONC
      QRSUM=QRSUM+R(L)*R(L)*QR*F(L)*CONC
   56 QSSUM=QSSUM+R(L)*R(L)*QS*F(L)*CONC
   57 CONTINUE
      QTSUM=QTSUM*PI
      QRSUM=QRSUM*PI
      QSSUM=QSSUM*PI
      ALBDO=QSSUM/QTSUM
      CAYNG=-CAY
      PFACT= WAVE*WAVE/(PI*QTSUM*EMM*EMM)
      DO58 J=1,IT
   58 PSUM(J)= PSUM(J)*PFACT/(4.*PI*ALBDO)
      IF(NINDX.GE.2)WRITE(6,23)
```

```
      WRITE(6,8)IDSTP,WAVE,EM ,CAYNG,QTSUM,QSSUM,ALBDO
      QTSUM=QTSUM*DENS*1.0E-06
      QSSUM=QSSUM*DENS*1.0E-06
      QRSUM=QRSUM*DENS*1.0E-06
      WRITE(6,28)QTSUM,QSSUM,QRSUM
      WRITE(6,29)GNU,DENS
      WRITE(6,9)
      WRITE(6,10)((C(J),PSUM(J)),J=1,IT)
C     IF (IOUT.LT.1)GO TO 61
C     DO 59 J=1,IOUT,4
C     WRITE(6,10)C(J),PSUM(J),C(J+1),PSUM(J+1),C(J+2),PSUM(J+2),C(J+3),
C    *PSUM(J+3)
   59 CONTINUE
      RETURN
   61 STOP
      END
      SUBROUTINE FMIEG2(EM,CAY,ALPHA,SGT,SGS,SGR,P,MCRTE,KKK)
      DIMENSION C(100),EYE1(100),EYE2(100),P(100)
      DIMENSION REAN(250),REBN(250),FAN(250),FBN(250)
      COMMON/BK2 /              C,   ALBDO,LLLL,NCRDS,IT,ITT,NRADI
      PIE=3.1415926535898
      EN=1.
      S=1.
      ISW1=1
      SUMT=0.
      SUMS=0.
      SUMRR=0.
      SUMRI=0.
      SUMS1=0.
      SUMS2=0.
C   MIE SERIES CUTOFF CRITERION
      FACT=1.2
      IF(ALPHA.GT.51.0)FACT=1.0    +2.26     *ALPHA**(-.613)
      A=EM*ALPHA
      B=A*CAY
      GAMMA=EM*CAY
      SINA= SIN(A)
      COSA= COS(A)
      COSHB=( EXP(B)+ EXP(-B))/2.
      SINHB=( EXP(B)- EXP(-B))/2.
       AB=A*A+B*B
      RNL1=SINA*COSHB
      SNL1=-COSA*SINHB
      TNL1= SIN(ALPHA)
      UNL1= COS(ALPHA)
C   THESE ARE THE BESSEL FUNCTONS OF N=1 ORDER
      RN=(RNL1*A-SNL1*B)/AB-COSA*COSHB
      SN=(RNL1*B+SNL1*A)/AB-SINA*SINHB
      TN=TNL1/ALPHA-UNL1
      UN=UNL1/ALPHA+TNL1
      GO TO 2
    1 TWONL1=2.0    *EN-1.
      STEP7=TWONL1/AB
      STEP8=TWONL1/ALPHA
```

```
C   THESE ARE THE RECURRENCE RELATIONS FOR THE UNPRIMED FUNCTIONS AND...
      RN=STEP7*(A*RNL1-B*SNL1)-RNL2
      SN=STEP7*(B*RNL1+A*SNL1)-SNL2
      TN=STEP8*TNL1-TNL2
      UN=STEP8*UNL1-UNL2
C   ...FOR THE PRIMED FUNCTIONS
    2 RPN=RNL1-EN*(A*RN-B*SN)/AB
      SPN=SNL1-EN*(B*RN+A*SN)/AB
      TPN=-EN*TN/ALPHA+TNL1
      UPN=-EN*UN/ALPHA+UNL1
C   REFERENCE LIGHT SCATTERING... BY VAN DE HULST
C   P123 FOR AN AND BN
      N=EN
      EKSN=RN*TPN-EM*RPN*TN-GAMMA*SPN*TN
      CAPN=SN*TPN-EM*SPN*TN+GAMMA*RPN*TN
      EPSN=RN*TPN-SN*UPN+EM*(SPN*UN-RPN*TN)-GAMMA*(RPN*UN+SPN*TN)
      PHIN=RN*UPN+SN*TPN-EM*(RPN*UN+SPN*TN)-GAMMA*(SPN*UN-RPN*TN)
      EKSPN=RPN*TN-EM*RN*TPN-GAMMA*SN*TPN
      CAPPN=SPN*TN-EM*SN*TPN+GAMMA*RN*TPN
      EPSPN=RPN*TN-SPN*UN-EM*(RN*TPN-SN*UPN)-GAMMA*(RN*UPN+SN*TPN)
      PHIPN=RPN*UN+SPN*TN-EM*(RN*UPN+SN*TPN)+GAMMA*(RN*TPN-SN*UPN)
      W=EKSN/PHIN
C   THESE KEEP THE ANOS AND BNOS CLOSE TO 1,SINCE THE NUMERATORS AND
C   DENOMINATORS ARE INDIVIDUALLY LARGE
      X=CAPN/EPSN
      Y=CAPN/PHIN
      Z=EKSN/EPSN
      DENOM=EPSN/PHIN+PHIN/EPSN
      WP=EKSPN/PHIPN
      XP=CAPPN/EPSPN
      YP=CAPPN/PHIPN
      ZP=EKSPN/EPSPN
      DENMP=EPSPN/PHIPN+PHIPN/EPSPN
      REAN(N)=(WP+XP)/DENMP
      REBN(N)=(W+X)/DENOM
      FAN(N)=(YP-ZP)/DENMP
      FBN(N)=(Y-Z)/DENOM
      IF(MCRTE.EQ.67890)WRITE(6,19)REAN(N),FAN(N),REBN(N),FBN(N)
   19 FORMAT(1X,4(E20.10,10X))
      S=-S
      TONP1=2.0     *EN+1.
C   SEE P127
      SUMT=SUMT+TONP1*(REAN(N)+REBN(N))
      SUMS=SUMS+TONP1*(REAN(N)*REAN(N)+FAN(N)*FAN(N)+REBN(N)*REBN(N)+FB
     1N(N)*FBN(N))
      SUMRR=SUMRR+TONP1*S*(REAN(N)-REBN(N))
      SUMRI=SUMRI+TONP1*S*(FAN(N)-FBN(N))
      IF(EN.EQ.1.0)GO TO 6
      EK=EN-1.
      SUMS1=SUMS1+EK*(EK+2.     )*(RAN*REAN(N)+RBN*REBN(N)+PAN*FAN(N)+PBN
     **FBN(N))/EN
      SUMS2=SUMS2+(2.0     *EN-1.     )*(RAN*RBN+PAN*PBN)/(EN*EK)
    6 RAN=REAN(N)
      RBN=REBN(N)
```

```
      PAN=FAN(N)
      PBN=FBN(N)
      TERMN= ABS(REAN(N))+ ABS(FAN(N))+ ABS(REBN(N))+ ABS(FBN(N))
      IF(TERMN.GE.1.0E-9.AND.EN.LT.8.0     +FACT*ALPHA)GO TO 4
      GO TO(3,5),ISW1
    3 ISW1=2
    4 EN=EN+1.
      RNL2=RNL1
      SNL2=SNL1
      TNL2=TNL1
      UNL2=UNL1
      RNL1=RN
      SNL1=SN
      TNL1=TN
      UNL1=UN
      GO TO 1
    5 ALF2=ALPHA*ALPHA
C   QEXT=SGT       QSCAT=SGS       QABS=SGA     QRADAR=SGR    AVE  COS(O)=SGM
C           QPR=SGMP(SEE P128)
      SGT=2.0     *SUMT/ALF2
      SGS=2.0     *SUMS/ALF2
      SGA=SGT-SGS
      SGR=(SUMRR*SUMRR+SUMRI*SUMRI)/ALF2
      SGMAS=2.0     *(SUMS1+SUMS2)/SUMS
      SGMP=SGT-SGMAS*SGS
      DO 98 K=1,IT
      COST=C(K)
      SINT= SQRT(1.0     -COST*COST)
      PINL1=0.
      RHNL1=0.
      PIN=1.
      RHN=0.
      TAUN=COST
      SUMI1R=0.
      SUMI1I=0.
      SUMI2R=0.
      SUMI2I=0.
C   SUMMATION OF MIE SERIES
      DO 97 L=1,N
      EN= FLOAT(L)
      TWONL1=2.0     *EN-1.
      ENNP1=EN*(EN+1.)
      ENL1=EN-1.
      IF(L.EQ.1)GO TO 10
      PIN=(TWONL1*COST*PINL1-EN*PINL2)/ENL1
      RHN=TWONL1*PINL1+RHNL2
      TAUN=PIN*COST-SINT*SINT*RHN
   10 TONP1=2.0     *EN+1.
      SUMI1R=SUMI1R+TONP1*(REAN(L)*PIN+REBN(L)*TAUN)/ENNP1
      SUMI1I=SUMI1I+TONP1*(FAN(L)*PIN+FBN(L)*TAUN)/ENNP1
      SUMI2R=SUMI2R+TONP1*(REBN(L)*PIN+REAN(L)*TAUN)/ENNP1
      SUMI2I=SUMI2I+TONP1*(FBN(L)*PIN+FAN(L)*TAUN)/ENNP1
      PINL2=PINL1
      PINL1=PIN
```

```
      RHNL2=RHNL1
   97 RHNL1=RHN
   11 EYE1(K)=     (SUMI1R*SUMI1R+SUMI1I*SUMI1I)
      EYE2(K)=     (SUMI2R*SUMI2R+SUMI2I*SUMI2I)
      P(K)=     (EYE1(K)+EYE2(K))/2.0
   98 CONTINUE
      RETURN
```

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